

**What is claimed is:**

1. A system for estimating EGR mass flow, comprising:  
an exhaust gas recirculation (EGR) conduit fluidly coupling an intake manifold of  
5 an internal combustion engine to an exhaust manifold of said engine, said EGR conduit  
including a flow restrictor disposed between said exhaust manifold and said intake  
manifold;

means for determining a pressure differential across said flow restrictor;

10 means for determining a gas density value corresponding to a density of gas  
flowing through said flow restrictor;

means for determining an effective flow area of said flow restrictor; and

a control circuit determining a mass flow of EGR through said EGR conduit  
based on said pressure differential, said gas density value and said effective flow area.

2. The system of claim 1 wherein said flow restrictor comprises a flow  
restriction device disposed in line with said EGR conduit, said flow restriction device  
responsive to a flow control signal to correspondingly restrict EGR flow therethrough.

3. The system of claim 2 wherein said flow restriction device is an EGR  
valve.

4. The system of claim 3 wherein said EGR valve includes an EGR valve  
position sensor producing a position signal corresponding to a position of said EGR  
valve relative to a reference position;

25 and wherein said means for determining an effective flow area of said flow  
restrictor includes means for determining an effective flow area of said EGR valve  
based on said position signal.

5. The system of claim 4 further including:  
30 an engine speed sensor producing an engine speed signal corresponding to  
rotational speed of said engine; and

a pressure sensor producing a pressure signal corresponding to a pressure within said intake manifold;

and wherein said means for determining an effective flow area of said EGR valve includes means for determining said effective flow area of said EGR valve based further  
5 on said engine speed signal and said pressure signal.

6. The system of claim 2 further including:

an engine speed sensor producing an engine speed signal corresponding to rotational speed of said engine; and

10 a pressure sensor producing a pressure signal corresponding to a pressure within said intake manifold;

wherein said means for determining an effective flow area of said flow restrictor further includes a base effective flow area value associated therewith, said means for determining an effective flow area of said flow restrictor determining said effective flow area as a product of said base effective flow area and a multiplier based on said pressure signal and said engine speed signal.

7. The system of claim 2 wherein said means for determining a pressure differential across said flow restrictor includes a differential pressure sensor disposed across said flow restriction device, said differential pressure sensor producing a differential pressure signal indicative of a pressure differential across said flow  
20 restriction device.

8. The system of claim 7 further including:

25 a first conduit having a first end in fluid communication with said EGR conduit adjacent to one end of said flow restriction device and a second end in fluid communication with one end of said differential pressure sensor; and

a second conduit having a first end in fluid communication with said EGR conduit adjacent to an opposite end of said flow restriction device and a second end in fluid  
30 communication with an opposite end of said differential pressure sensor.

9. The system of claim 8 wherein said flow restriction device is an EGR valve.

10. The system of claim 2 wherein said means for determining a pressure differential across said flow restrictor includes:

a first pressure sensor producing a first pressure signal corresponding to a pressure within said intake manifold;

a second pressure sensor producing a second pressure signal corresponding to a pressure of exhaust gas within an exhaust gas flow structure of said engine; and

means for determining said pressure differential as a function of said first and second pressure signals.

11. The system of claim 1 wherein said flow restrictor comprises a flow restriction area of said EGR conduit sized to restrict EGR flow therethrough.

12. The system of claim 11 wherein said means for determining a pressure differential across said flow restrictor includes a differential pressure sensor disposed across said flow restriction area of said EGR conduit, said differential pressure sensor producing a differential pressure signal indicative of a pressure differential across said flow restriction area of said EGR conduit.

13. The system of claim 12 further including:

a first conduit having a first end in fluid communication with said EGR conduit adjacent to one end of said flow restriction area thereof and a second end in fluid communication with one end of said differential pressure sensor; and

a second conduit having a first end in fluid communication with said EGR conduit adjacent to an opposite end of said flow restriction area thereof and a second end in fluid communication with an opposite end of said differential pressure sensor.

14. The system of claim 1 wherein said means for determining a pressure differential across said flow restriction area of said EGR conduit includes:

a first pressure sensor producing a first pressure signal corresponding to a pressure within said intake manifold;

a second pressure sensor producing a second pressure signal corresponding to a pressure of exhaust gas within an exhaust gas flow structure of said engine; and

5 means for determining said pressure differential as a function of said first and second pressure signals.

15. The system of claim 11 further including:

an engine speed sensor producing an engine speed signal corresponding to rotational speed of said engine; and

a pressure sensor producing a pressure signal corresponding to a pressure within said intake manifold;

and wherein said means for determining an effective flow area of said flow restrictor includes means for determining an effective flow area of said flow restriction area of said EGR conduit based on said engine speed signal and on said pressure signal.

16. The system of claim 15 wherein said means for determining an effective flow area of said flow restriction area of said EGR conduit further includes a base effective flow area value associated therewith, said means for determining an effective flow area of said flow restriction area of said EGR conduit determining said effective flow area of said flow restriction area of said EGR conduit as a product of a multiplier based on said pressure signal and said engine speed signal and said base effective flow area value.

17. The system of claim 1 wherein said control circuit is configured to produce an EGR flow parameter (EGRFP) according to:

$$\text{EGRFP} = \sqrt{|(2 * \Delta P * \rho)|};$$

wherein  $\Delta P$  is said pressure differential and  $\rho$  is said gas density value.

18. The system of claim 17 further including:  
a pressure sensor producing a pressure signal corresponding to a pressure within said intake manifold; and  
5 means for determining a temperature of exhaust gas produced by said engine and producing a temperature value corresponding thereto;  
wherein said control circuit is configured to compute said gas density value  $\rho$  according to

$$\rho = (\text{IMP})/(\text{R} * \text{EXT})$$

wherein, IMP is said pressure signal, EXT is said temperature value, and R is a gas constant.

19. The system of claim 16 wherein said control circuit is configured to compute said mass flow of EGR as a product of said EGR flow parameter and said effective flow area.

20. The system of claim 1 further including a limiter operable to limit said mass flow of EGR between maximum and minimum EGR mass flow values.

21. The system of claim 1 further including:  
means for determining a mass flow of charge entering said intake manifold; and  
means for determining a fraction of said charge attributable to EGR as a function  
25 of said mass flow of EGR through said EGR conduit and said mass flow of charge entering said intake manifold.

22. The system of claim 21 further including:  
means for determining a volumetric efficiency of said intake manifold; and  
30 means for determining a delayed EGR flow value as a function of said engine speed and said volumetric efficiency;

and wherein said means for determining said fraction of charge attributable to EGR is operable to determine said fraction as a function of said mass flow of charge entering said intake manifold and said delayed EGR flow value.

5           23.    A system for estimating EGR mass flow, comprising:  
          an exhaust gas recirculation (EGR) conduit fluidly coupling an intake manifold of  
          an internal combustion engine to an exhaust manifold thereof, said EGR conduit  
          including an EGR valve disposed between said exhaust manifold and said intake  
          manifold;  
10           an EGR valve position sensor producing a position signal indicative of EGR valve  
          position relative to a reference position;  
          means for determining a pressure differential between said exhaust and intake  
          manifolds; and  
          a control circuit determining EGR mass flow through said EGR conduit based on  
          said position signal and said pressure differential.

20           24.    The system of claim 23 wherein said control circuit includes a limiter  
          operable to limit said EGR mass flow between maximum and minimum EGR mass flow  
          values.

25           25.    The system of claim 23 further including:  
          means for determining a mass flow of charge entering said intake manifold; and  
          means for determining a fraction of said charge attributable to EGR as a function  
          of said mass flow of EGR through said EGR conduit and said mass flow of charge  
          entering said intake manifold.

30           26.    The system of claim 25 further including:  
          means for determining a volumetric efficiency of said intake manifold; and  
          means for determining a delayed EGR flow value as a function of said engine  
          speed and said volumetric efficiency;

and wherein said means for determining said fraction of charge attributable to EGR is operable to determine said fraction as a function of said mass flow of charge entering said intake manifold and said delayed EGR flow value.

5           27.    A system for estimating EGR mass flow, comprising:  
            an exhaust gas recirculation (EGR) conduit fluidly coupling an intake manifold of  
            an internal combustion engine to an exhaust manifold thereof, said EGR conduit  
            including an EGR valve disposed between said exhaust manifold and said intake  
            manifold;  
10           an EGR valve position sensor producing a position signal indicative of EGR valve  
            position relative to a reference position;  
            means for determining a pressure ratio between said exhaust and intake  
            manifolds;  
            means for determining a temperature of exhaust gas produced by said engine  
            and producing a temperature value corresponding thereto; and  
            a control circuit determining EGR mass flow through said EGR conduit based on  
            said position signal, said pressure ratio and said temperature value.

15           28.    The system of claim 27 wherein said means for determining a pressure  
            ratio between said exhaust and intake manifolds includes:  
            a pressure sensor producing a pressure signal corresponding to a pressure  
            within said intake manifold; and  
            means for determining a pressure differential between said exhaust and intake  
            manifolds; and  
25           means for computing said pressure ratio as a function of said pressure signal  
            and said pressure differential.

30           29.    The system of claim 28 wherein said means for determining a pressure  
            differential between said exhaust and intake manifolds includes a differential pressure  
            sensor having a first end in fluid communication with said EGR conduit adjacent to one

end of said EGR valve and a second end in fluid communication with said EGR conduit adjacent to an opposite end of said EGR valve.

30. The system of claim 27 wherein said means for determining a pressure  
5 ratio between said exhaust and intake manifolds includes:

a first pressure sensor producing a first pressure signal corresponding to a pressure within said intake manifold;

a second pressure sensor producing a second pressure signal corresponding to a pressure within an engine exhaust structure; and

10 means for computing said pressure ratio as a ratio of said first and second pressure signals.

31. The system of claim 27 wherein said control circuit includes:  
means for producing a corrected EGR flow parameter value as a function of said  
position signal and said pressure ratio;

means for determining a pressure within an engine exhaust structure of said engine and producing an exhaust pressure value corresponding thereto;

means for producing a square root of said temperature value; and

means for determining said EGR mass flow as a product of said corrected EGR flow parameter and said exhaust pressure value divided by said square root of said temperature value.

32. The system of claim 31 wherein said control circuit includes a limiter operable to limit said EGR mass flow between maximum and minimum EGR mass flow  
25 values.

33. The system of claim 27 further including:  
means for determining a mass flow of charge entering said intake manifold; and  
means for determining a fraction of said charge attributable to EGR as a function  
30 of said mass flow of EGR through said EGR conduit and said mass flow of charge entering said intake manifold.



34. The system of claim 33 further including:

means for determining a volumetric efficiency of said intake manifold; and

means for determining a delayed EGR flow value as a function of said engine

5 speed and said volumetric efficiency;

and wherein said means for determining said fraction of charge attributable to EGR is operable to determine said fraction as a function of said mass flow of charge entering said intake manifold and said delayed EGR flow value.

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